Aging Systems Research Program

- Federal Aviation Administration
- William J. Hughes Technical Center

- 28 September 2000

- Robert A. Pappas
- AAR-433
- Airworthiness Assurance R&D

Program Objective

Develop technologies and techniques to ensure the continued safe operation of aircraft electrical and mechanical systems.

Support pending/new regulatory action and facilitate compliance with existing and new regulations.

Program History

White House Commission on Aviation Safety & Security

- Expand the Aging Aircraft Program
  - ✓ Electrical wiring, connectors, harnesses
  - ✓ Fuel, hydraulic, and pneumatic lines
  - ✓ Electromechanical systems (pumps, sensors, actuators, etc.)

FAA Aging Transport Non-Structural Systems Plan

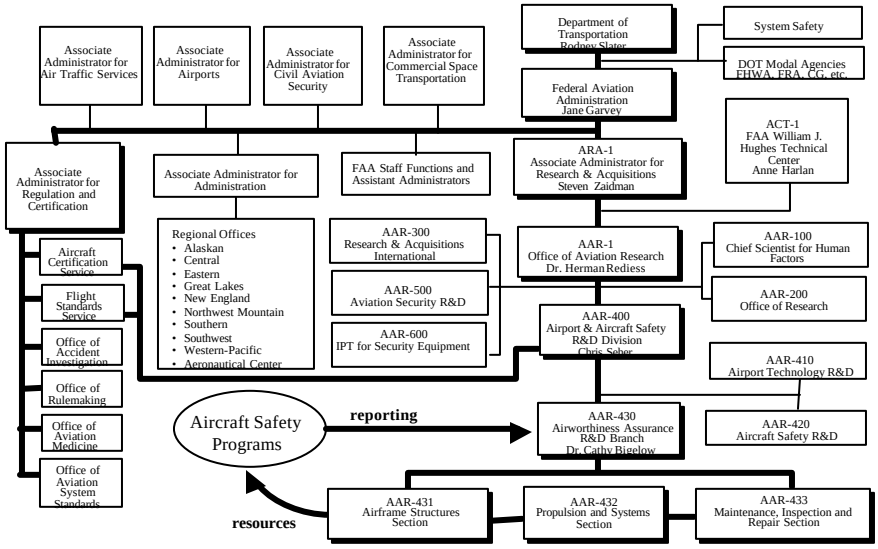
- Task 4: Add aging systems research to the aging airplane research program

Program History

FAA Aging Transport Non-Structural Systems Plan

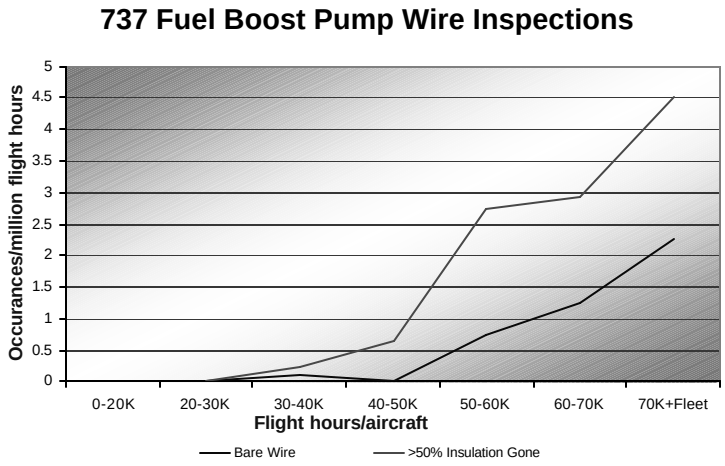
- Characterize wire degradation
- Validate adequacy of visual inspection and establish condition of aging wiring components
- Develop non-destructive test (NDT) tools for inspection of wiring **systems**
- Develop an arc fault circuit breaker
- Establish aging effects on lightning and HIRF protection systems
- Destructive testing of flight control systems

Organization

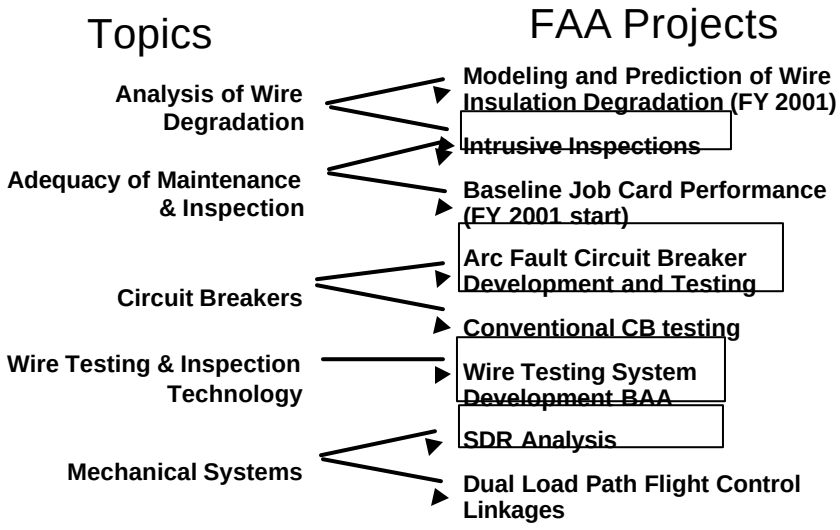


WHY AGING ELECTRICAL SYSTEMS RESEARCH?

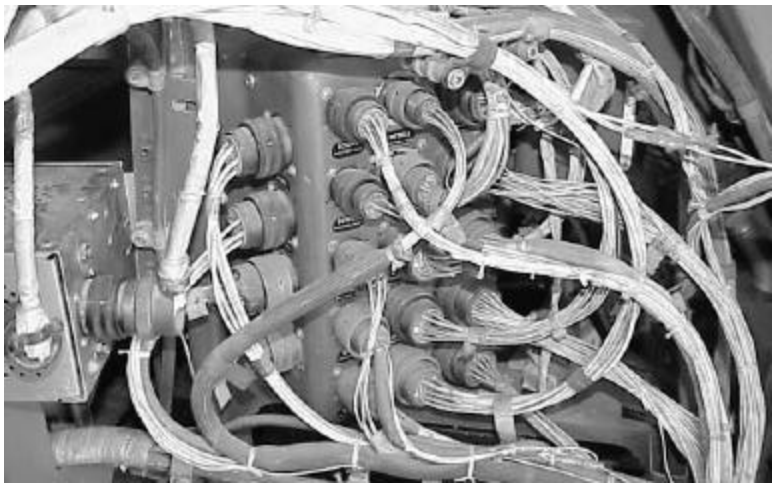
Age Related Wire Failures



Presentation Outline



Aging Electrical Systems



Visual Inspection

Mandate: “Establish condition of aging system wiring components and validate the adequacy of visual inspection.”

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Issues:

- Visual Inspection for debilitating traumatic damage:
  - perception of failure condition itself (e.g. chaffed wire)
  - perception of conditions leading to failure (e.g. contamination)
- Visual Inspection for determination of susceptibility to proximate failure or observation of proximate failure itself:
  - According to Bruning, visual clues may be weak or nonexistent.

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Initiatives:

- ATA-FAA intrusive inspection of retired aircraft wire installations (on-going)
  - More intensive examination than in-service supplemental inspections
  - Visual inspection backed-up with destructive and other supplemental analysis
- Baseline job-card performance (future)
  - The intrusive inspections will establish the efficacy of an ideal visual inspection. This task will assess the efficacy of visual inspection as applied in the field

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Overview

- Rigorous protocol addressing 14 characteristic locations across several aircraft types. (Where possible locations correspond with non-intrusive inspection protocol.)
- Enhanced inspections to assess insulation electrical properties, insulation mechanical properties, other degradation related parameters.

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

- Specimen Types
  - ✓ Interior and Exterior of Pressure Vessel
  - ✓ Bilge and Crown Areas
  - ✓ High/Low Maintenance Locations and Installations
  - ✓ Bundles Exposed and In Conduit
  - ✓ Straight Runs and Complex Harnesses
  - ✓ Small and Large Bundles
  - ✓ Small Gage and Large Gage Wire (Power Feeders)

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Laboratory Testing

Sandia National Labs	Raytheon	FAA/USAF
• Optical Microscopy • Mandrel Bend screening • Density Measurements • Modulus Profiling • Insulation Tensile S And E • Solvent Swelling • Infrared Spectroscopy • Chemiluminescence • Oxygen Induction Time • Thermo-Oxidative Wear-Out	• Mandrel and Wrap Back Test • Wet Dielectric – Voltage Withstand • Conductor Resistance • Insulation Resistance • Inherent Viscosity Test • Dynamic Cut-Through • Lamination Sealing • Cross Link Proof Test	• Dry Arc Tracking • Wet Arc Tracking • Flammability • X-ray

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Task schedule

- ✓ 6/99 - 9/99 Development and Validation of Protocols
- ✓ 9/99 - 6/00 Intrusive Inspection of six aircraft
- ✓ 12/99 - 7/00 NDT of six aircraft
- ✓ 5/00 - 8/00 Laboratory analysis of wire specimens
- 9/00 Report to ATSRAC

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Status

All six aircraft have been subject to the detailed visual inspection and on-aircraft nondestructive testing:

Aircraft	A300	DC-9$_{(1)}$	747	DC-9$_{(2)}$	L1011	DC-10
Inspection	09/99	11/99	01/00	05/00	06/00	06/00
Year mfg.	1978	1967	1973	1971	1972	1979
Hours	40,000	75,000	100,000	66,800	63,600	61,300
Retired	07/99	08/99	05/99	12/99	06/99	
Wire	PI	P/G/N	PolyX	P/G/N	PI	XL-ETFE

Intrusive Inspection Project

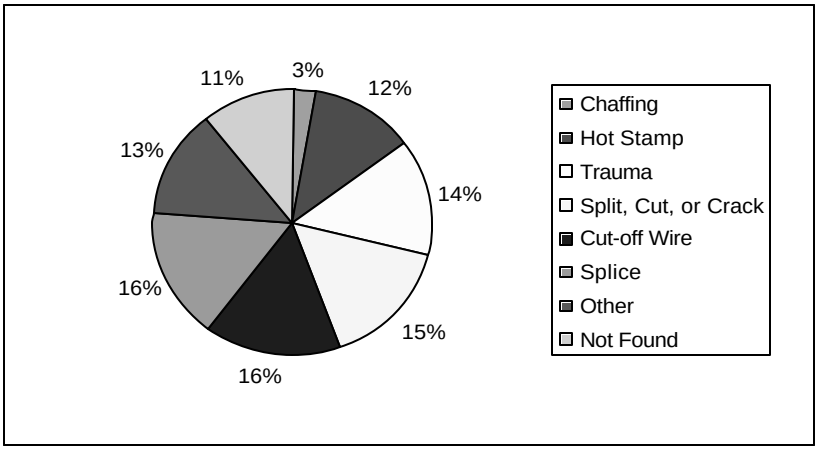
(Visual Inspection/Wire Degradation Characterization)

	A300	**DC-9$_{(1)}$**	**747**	**DC-9$_{(2)}$**	**L1011**	**DC-10**
No. Preselected wires	2083	718	1003	394		
Length of Preselected (ft)	7973	4001	6075	1986		
Total Visual Finds	60	123	150	116		
Visual Finds of Preselected	4	29	9	12		
Finds by Eclypse	29	51	25	?		
Finds by DelTest	20	4	14	10		
Eclypse Finds per 1000 wire	40.4	50.9	63.5			
DelTest Finds per 1000 ft	2.5	1.0	2.3	5.0		

Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

DelTest Flaw Type Distribution



Intrusive Inspection Project

(Visual Inspection/Wire Degradation Characterization)

Working Group Output

- Flaws to be categorized as unique, infrequent, or common. Each class handled separately.
- Working Group will use a formal threat assessment procedure.
- In judging the threat, consideration will be given to:
  - Aggravating or contributory factors
  - Wire insulation type
  - Estimated probability of existence
- In making recommendations consideration will be given to:
  - Visual detectability
  - Efficacy of other inspection or testing

Wire Degradation

Mandate: Characterize the degradation of aged aircraft wire. For known service conditions, determine thresholds at which wire integrity becomes suspect.

Wire Degradation

Task Outline:

- Failure criteria, experimental procedures, and significant test parameters will be reviewed by a broad-based oversight group, ensuring the relevance of the effort.
- This initiative will use a meta-statistical approach which formally combines the results of several different experiments (pursuing the same objectives and adhering to the same 'ground rules'). This will help to ensure the integrity and credibility of the results.
- New start, FY-01

Wire Degradation

Issues:

Wire life depends on:

- wire type (likely candidates for this initiative are: polyimide, poly-X, PVC/glass/Nylon, polyalkene);
- service environment (temperature, humidity, contamination, etc.);
- the failure criteria; and,
- other (unknown or unknowable) factors.

The impact of “other factors” will determine the feasibility of assessing degradation limits.

Wire Degradation

Discussion:

Failure criteria may be relative (having an arbitrarily selected threshold or thresholds which when exceeded indicate failure) or absolute (having no threshold).

Some Relative Failure Criteria (threshold dependent):

- conductor resistance (SAE 4373/403).
- voltage withstand (SAE 4373/510).
- mandrel and wrap-back test (SAE 4373/703).

Some Absolute Failure Criteria (no threshold):

- insulation breach.

Wire Degradation

Approach:

- Identify perturbations to the aging process (i.e. the ‘unknown’ or ‘unknowable factors’).
- Identify accelerated aging process.
- Design experiment constraints/acquire materials.
- Assign experiment responsibility (~3 organizations with established credibility in this area).
- Analyze results/correlate with other findings.

Wire Degradation

Task Risks:

- Failure to establish a class of failure criteria broadly acceptable to the aviation community will result in wire life estimates with disputable applicability.
- Too broad a class of failure criteria will result in meaningless or statistically questionable results.

Wire Degradation

Northwestern University

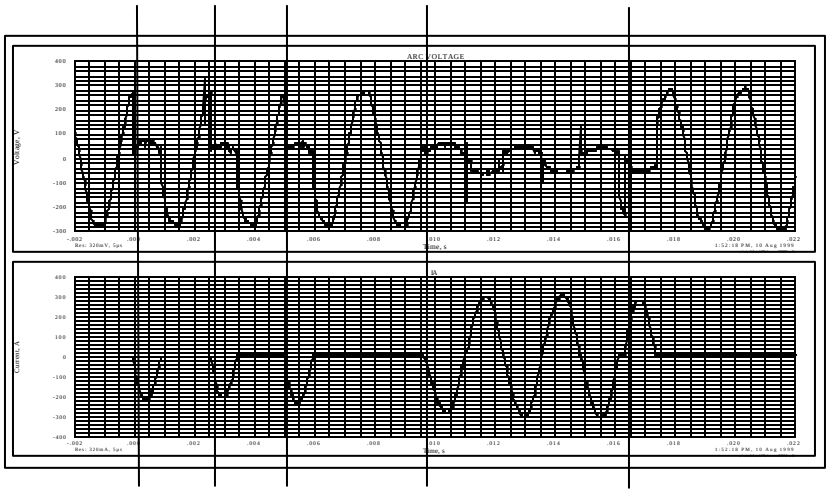
- Aging Characterization and Lifetime Assessment of Polymeric Insulation in Aircraft Wiring.
- Impedance Spectroscopy correlated with FTIR spectroscopy and microscopy techniques.
- Three year effort.
- Congressionally earmarked funds.

AFCI

Mandate: "Develop an Arc Fault Circuit Interrupter (AFCI)"

AFCI

What is an arc?



Time from first arc to end of last arc: 17.5 ms

AFCI

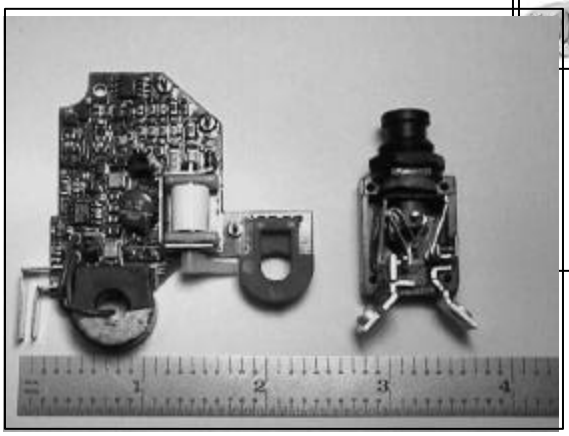
AFCI Objective:

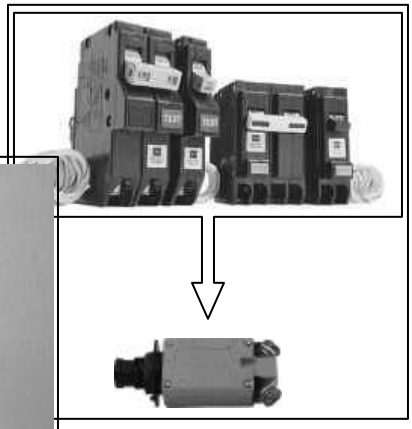
- Develop a form, fit, function replacement for existing breakers
- Incorporate arc fault detection and retain thermal tripping elements

Most significant breaker design change in over 30 years.

AFCI

Challenge: Miniaturization





AFCI

Task Outline:

- Joint effort with the Office of Naval Research and NAVAIRSYSCOM.
- 3 year effort resulting in airworthy product.
- Contracts awarded 12/99 to Eaton Aerospace and Hendry Telephone Products
- Boeing AFCB Project

AFCI

Status:

- Both contractors have demonstrated their algorithms for detection of phase to phase, phase to ground, and series arcs.
- 727 Load characterization tests at Tech Center 07/31 – 08/04
  - ✓ early prototypes tested on the 727 to evaluate nuisance tripping
- Boeing flight tests begin: September/October 2000.
- Present data indicate that the AFCB circuitry can be fit into smaller breakers
- FAA initiated development of an AFCB standard with the SAE.

AFCI

Plans:

- Boeing flight tests in late 2000
- SAE AFCB Working Group meeting in October ’00
- Additional ground testing on a Navy C-9 and FAA Boeing 747 (Sandia)
- Government safety of flight tests (FY-01)
- Navy and FAA flight testing (Mid FY-01)
  - C-9 (Navy)
  - 727 (FAA)
- FAA rulemaking activity – Draft AC and TSO (FY-01)

Aging Circuit Breakers

Task Outline:

- Conduct a series of tests on thermal, single phase circuit breakers removed from intrusive inspection aircraft.
- Determine if aging has degraded the performance of the circuit breakers and if so the follow-on research necessary to fully evaluate the degradation process.

Aging Circuit Breakers

Status:

- Sandia National Labs contracted to perform tests.
- 43 breakers from 4 manufacturers tested from the DC-9, A300, and B747 intrusive inspection aircraft
- Approximately 35% of breakers did not trip
- ANM-100 and AIR-1 have been briefed
- Texas Instruments conducting failure analysis
- Further testing will be conducted pending the development of a revised test plan

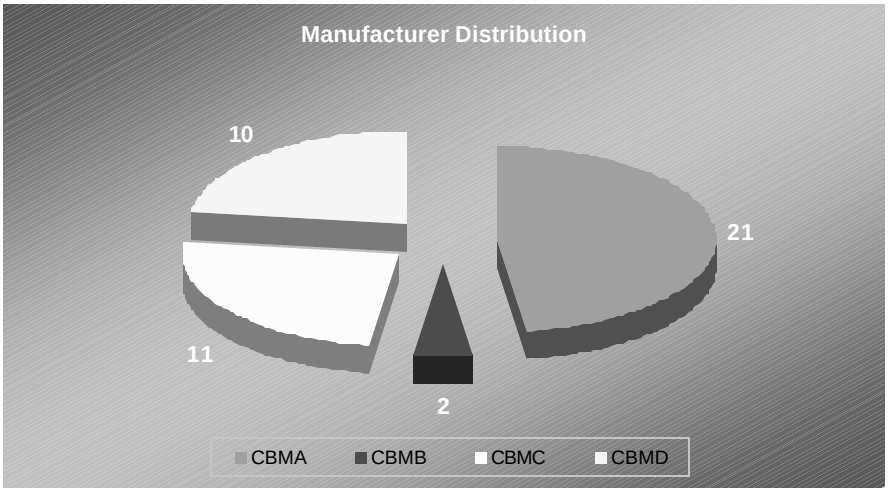
Aging Circuit Breakers

AC 43.13-1B, Para. 11-52

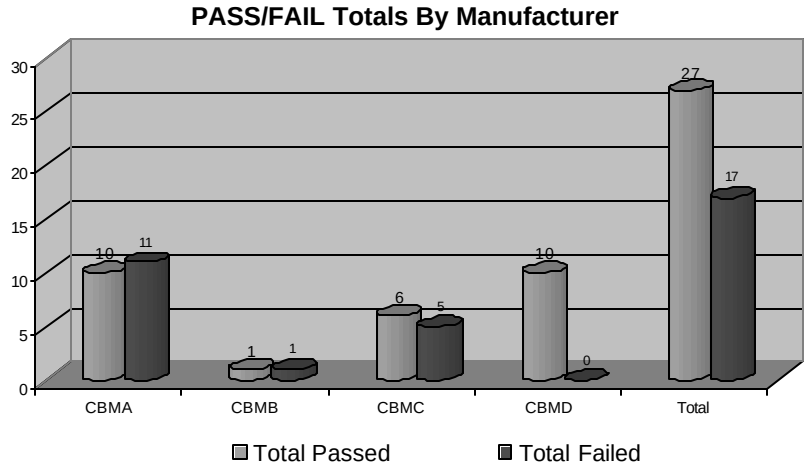
<u>Circuit Breaker Maintenance</u>

Circuit breakers should be periodically cycled with no load to enhance contact performance by cleaning contaminants from the contact surfaces.

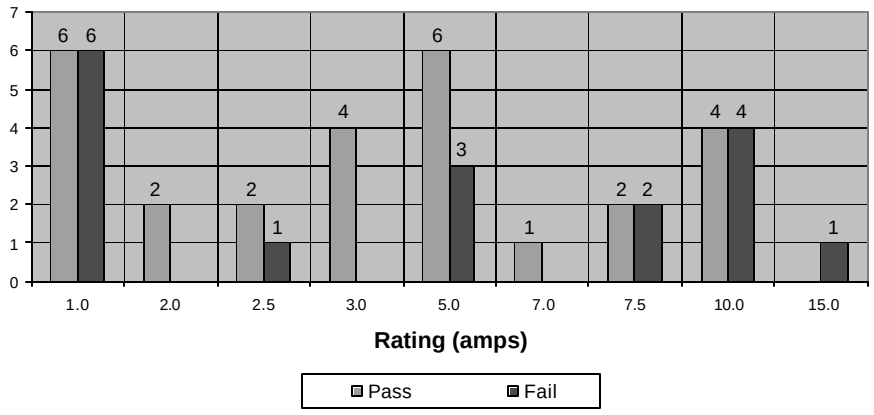
Aging Circuit Breakers



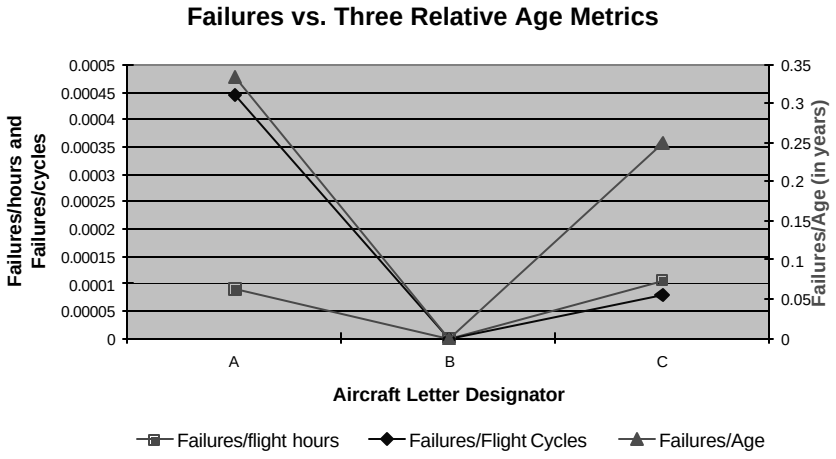
Aging Circuit Breakers



Aging Circuit Breakers



Aging Circuit Breakers



Aging Circuit Breakers

Non-Destructive Test Tools

Mandate: “Development of Non-destructive Test tools for inspection of wiring systems.”

Non-Destructive Test Tools

Project Outline:

- Use the Sandia 747 test bed to validate FAA-sponsored and other inspection systems.
- Progress: Completed evaluation of GRC/Eclypse enhanced automatic test system.
- Future tasks: competitive awards to be made in FY 2000 – 2003.

Non-Destructive Test Tools

Future Tasks - Proposed Approach:

- **Annual issuance of a BAA**
- **Define device to measure:**
  - ✓ physical properties/material anomalies
  - ✓ local/bulk electrical properties or performance
  - ✓ other relevant conditions or properties
- **Collaborate with aviation partner(s)!**
- **Identify wire type/failure criteria.**
- **Correlate measured quantities with failure criteria.**
- **Design, build, and test device.**

Non-Destructive Test Tools

FY-00 BAA Status:

- **24 summary proposals received.**
- **8 full proposals received and reviewed.**
- **Two contracts awarded.**
- **Selected technologies are Time Domain Reflectometry (TDR), Standing Wave Reflectometry (SWR), and Broadband Impedance Measurement.**

Non-Destructive Test Tools

- BAA: Summary of proposed technologies
  - Time Domain Reflectometry
  - Broad Band Impedance Monitoring/Spectroscopy
  - Integration of COTS devices
  - Frequency Domain Reflectometry
  - DelTest™ Improvements
  - Standing Wave Reflectometry
  - Indenter

Non-Destructive Test Tools

Time Domain Reflectometry

- **ECAD/CM Technologies**
- **Excited Dielectric Test – Four Measurements**
  - **Non-energized**
  - **Energized**
  - **Energized at ± frequency (TBD)**
- **Modeling of faults**
- **12 month effort**
- **Validation/blind testing at AANC, Albuquerque**

Non-Destructive Test Tools

Standing Wave Reflectometry (SWR) and Broadband Impedance Measurement

- **Boeing, Rockwell Science Center, Eclypse**
- **SWR**
  - **Accurately locates shorts and high impedance faults**
  - **NASA patents licensed by Eclypse**
  - **Hand-held unit**
- **Modeling of faults**
- **42 month effort**
- **Validation/blind testing at AANC, Albuquerque**

SDR Analysis

Objective:

Identify potential system safety issues by an analysis of SDR data.

SDR Analysis

Approach

- Acquire SDR data from 1985 through 1999
- Exclude all but currently aged transports
- Exclude non-relevant ATA Chapters
- Divide into groups of reports 9 to 14 years since mfr and 20 to 24 years since mfr.
- Look for trends by model, ATA code, part description, part condition.

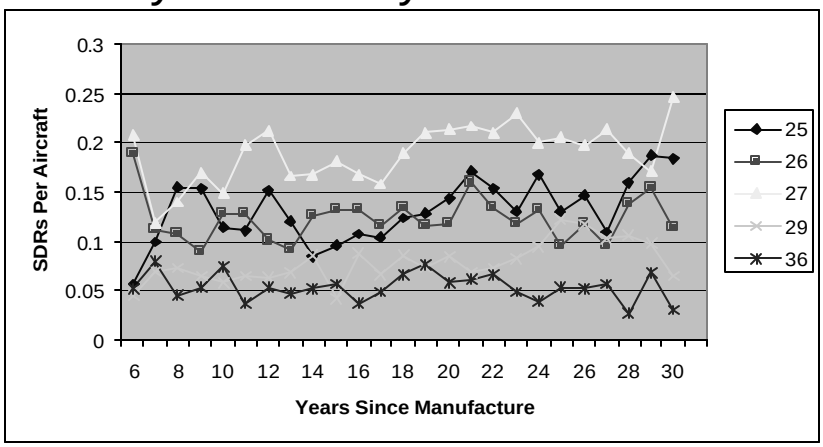
SDR Analysis

Supplemental Analysis

- Identify trends in the nature of failure (i.e. the failed part's condition).
- Identify trends in the severity of failure.
- Test analysis on an already well analyzed issue – wire failure.

SDR Analysis

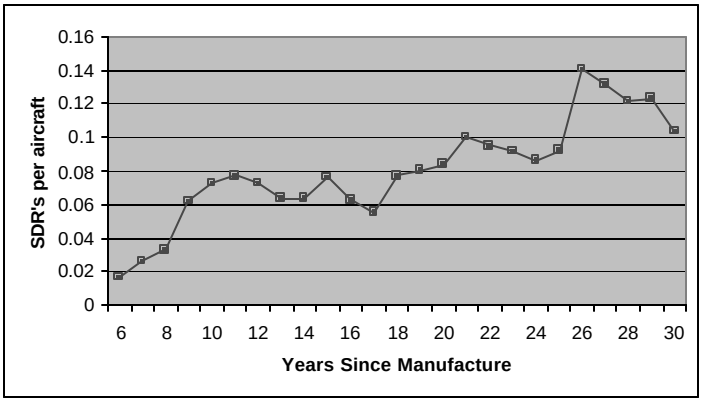
Primary Data Analysis



Rate Of SDR Reporting By System Versus Age Of Aircraft

SDR Analysis

- Does this analysis work for wire?



SDR reports for aging transports containing reference to wire, wiring, electrical cabling as a function of years since aircraft manufacture.

SDR Analysis

Conclusions

- Service Difficulty Reporting (non-routine service reporting) does not contain readily apparent trend data that supports the notion of severe mechanical systems degradation either overall or in specific systems or components.
- This statement should not be more broadly interpreted to imply the absence of significant mechanical systems degradation.

Aging Systems Test Bed AANC/Sandia

http://aar400.tc.faa.gov/agingsystems/